Journal of Forestry Research (2012) 23(2): 253−260
DOI 10.1007/s11676-012-0251-7

ORIGINAL PAPER

Soil microbial biomass and population in response to seasonal variation and age in *Gmelina arborea* plantations in south-western Nigeria

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Received: 2010-05-06 Accepted: 2011-10-12

Abstract: We investigated the Effects of plantation development, seasons, and soil depth on soil microbial indices in *Gmelina arborea* plantations in south-western Nigeria. Soil samples were obtained from the soil depths of 0–15 and 15–30 cm from plantations of six different ages during the rainy season, dry seasons, and their transitions. We used plate count and fumigation–extraction methods to determine microbe population and microbial biomass carbon (MB-C) and nitrogen (MB-N), respectively. Plantation age did not affect microbial indices, implying a non-significant effect of plantation development on microbial communities. It could also imply that soil microbial indices had already stabilized in the sampled plantations. Seasonal variation and soil depth had significant effects on microbial indices. At 0–15 cm soil depth, mean MB-C increased from 50.74 $\mu g \cdot g^{-1}$ during the peak of the dry season (i.e. March) to 99.58 $\mu g \cdot g^{-1}$ during the peak of the rainy season (i.e. September), while it increased from 36.22 $\mu g \cdot g^{-1}$ to 75.31 $\mu g \cdot g^{-1}$ at 15–30 cm soil depth between the same seasonal periods. Bacteria populations and MB-N showed similar increasing trends. Correlations between MB-C, MB-N, microbe populations, and rainfall were positive and linear. Significantly higher microbial activities took place in the plantations during the rainy season, increased with soil wetness, and decreased at greater soil depth.

Keywords: *Gmelina arborea*; plantation development; seasonal variation; microbe population; microbial biomass; sustainability; Nigeria

Introduction

Vast areas of forestland are degraded annually and rendered unproductive through human activities throughout the world. This is particularly alarming in the tropics where forest degradation and subsequent conversion to non-forest uses proceeds at unprecedented rates (FAO 2010; FAO 2011). The conversion of forest to farms and pastures is one of the main causes of deforestation in the tropics. In developing countries, a high percentage of farmers practice shifting cultivation. Thus, encroachment into forest ecosystems by farmers in search of more fertile and productive land will continue unless the practice of shifting cultivation is controlled or halted. The conversion of degraded natural forests to forest plantations is one method used to prevent or minimise encroachment into degraded forests by farmers and thus ensuring that the land remains under forest cover.

Globally, the area of forest plantations has increased since the middle of the 20th century, especially within the past four decades (Evans et al. 2004; FAO 2010). The increasing trend of forest plantations has resulted in a significant increase in their share of global forest area. The contribution of forest plantations to global forest area increased from 3% in 1995 to 5% in 2000 and 6.6% in 2010 (Carnus et al. 2006; FAO 2010; FAO 2001). Considering the increasing annual establishment rates (from 0.25×10^6 $ha \cdot a^{-1}$ in 1970; 4.5×10^6 $ha \cdot a^{-1}$ between 2000 and 2005; 4.4×10^6 $ha \cdot a^{-1}$ between 2005 and 2010), (Pandey 1987; FAO 2001; FAO 2010), and the increasing contribution of forest plantations to global wood supply, the area under forest plantations is expected to further increase in the 21st century. The fast growth rates of most plantation tree species and their ability to produce high amounts of biomass within a relatively short period of time have been noted as probable reasons for the continued growth in plantation area. Higher biomass production per unit area has been reported in forest plantation compared to natural forests (Evans 1999; Evans et al. 2004). This high biomass production and fast growth rates of forest plantation species have raised concern about the sustainability of forest plantation sites (Evans 1998; Mishra et al. 2003; Onyekwelu et al. 2006; Onyekwelu 2011).

Sustainability of forest plantation site is defined as: the long-term use of the plantation site is maximized to the extent that the nutrient resource base, structure or function of the eco-

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Responsible editor: Zhu Hong

system is not degraded. Thus, for a plantation site to be sustainable, there should be no significant negative changes in soil physical, chemical, or biological conditions. In managed forests, the inherent site potential is largely determined by soil characteristics and climatic factors (Skovsgaard et al. 2008). Soil microbe populations play fundamental role in ecosystem functioning, as they decompose organic matter, determining the release of mineral nutrients in the soil and influencing primary productivity and nutrient cycling. It is an indication of soil biological productivity and measurable changes in microbial biomass and may reflect changes in soil fertility (Brookes 2001).

The passage of seasons may influence microbe populations and microbial biomass directly, through changes in microclimate, or indirectly, by influencing plant metabolism that feeds back to the soil ecosystem (Behera et al. 2003; Verburg et al. 1999). Soil microbes and their biomass have remained largely unexplored in *G. arborea* plantations in the study area, despite the impact of the soil microbes on soil fertility in forest ecosystems and their importance in maintaining biological systems for regulation of decomposition (Brookes 2001). In the present study, we investigated the effect of plantation development (age), seasonal variation, and soil depth on soil microbe populations and microbial biomass in an age series of *G. arborea* plantations in south-western Nigeria.

Materials and methods

The study area

The study was conducted at Oluwa Forest Reserve in south-western Nigeria (latitude 6°55' to 7°20' N and longitude 4°32' to 4°45' E). The reserve's topography is relatively flat with an average elevation of 100 m above sea level. Rainy season lasts April to November, with mean annual rainfall of 1,700 to 2,200 mm. Dry season lasts from December to March. Mean annual temperature and daily relative humidity are 26ºC and 84%, respectively. The soils of Oluwa are classified as Alfisols (SSS 2003). The soil parent materials were formed from crystalline rocks of undifferentiated basement complex of pre-cambrian series. The soils are well-drained, mature, red, stony and gravely in the upper parts of the sequence (Smyth et al. 1962; Onyekwelu et al. 2006). Topsoil is sandy loam, which becomes heavier at lower soil depths. Sub-soil consists of clay with gravel occurring at 30–60 cm soil depths.

Land-use pattern and plantation development

Following degradation and designation of Oluwa forest reserve as "low-value, logged-over high forest", the reserve of about 87,816 ha was designated for plantation establishment. However, only a little over 20,000 ha of plantations have been established in the reserve to date. About 27,000 ha of the reserve are still covered by degraded natural forests, while about 31,000 ha are covered by farmlands. The remaining part of the reserve (about 11,000 ha) is primary forest (a small portion), rock outcrops, and water bodies.

Evidence of plantation trials in Oluwa dates back to the early 20th century and involved mostly indigenous species such as *Nauclea diderrichii*, *Terminalia* spp., Mahoganies, *Lophira alata*, and others. By the second decade of the 20th century, some exotic species (e.g. *Tectona grandis* and *G. arborea*) were tried and found promising. Large-scale plantation establishment with *Gmelina* began in the late 1960s. During this early stage and until 1979, over 5000 ha of mainly *Gmelina* plantations were established in Oluwa. By 1980, the Ondo State Afforestation Project (OSAP) was initiated in Oluwa. By 1996, the project had established about 14,331 ha of *Gmelina* plantations. Also, about 1,235 ha, 204 ha, and 892 ha of *Tectona grandis*, *Pinus caribaea* and some indigenous species (mainly *N. diderrichii*) were established. Plantation establishment currently continues on a small scale in Oluwa. *Gmelina* is the dominant plantation species in Oluwa, accounting for over 19,000 ha (about 90%) of total plantation area in the reserve.

Data collection

Six different ages (13 to 25 years) of *G. arborea* plantations were selected for this study. As much as possible, selected plantations were evenly distributed within the age bracket stated above to capture the various stages of development. The chosen plantations were divided into 20 m × 20 m temporary sample plots, from which four were randomly selected. All sample plots were sampled four times between 2007 and 2008 and covered the onset and peak of rainy (April and September) and onset and peak of dry (November and March) seasons. A diagonal line was laid within the 20 m × 20 m sample plots and soil samples were collected from three points (i.e. the two edges and middle of the line) along the diagonal line at two soil depths of 0–15 and 15–30 cm. Samples from similar soil depths in each plot were thoroughly mixed, from which composite samples were collected. To prevent the soils from drying out and negatively affecting microbial activity, the samples were kept in nylon bags that were covered with moistened sand.

Laboratory analyses

Prior to analysis, soil samples were sieved with a 2-mm sieve and stored at 4°C. Microbial isolations were done on fresh soil samples using the standard procedure adopted by Kader et al. 1999; Wirth and Ulrich, 2002 (both cited by Oseni et al. 2007). Soil microbial biomass Carbon (MB-C) and Nitrogen (MB-N) were estimated following the fumigation–extraction procedure of Amato and Ladd (1988) as modified by Joergensen and Brookes (1990) and Ocio and Brookes (1990). MB-C and MB-N were estimated using a factor of 31 and 4.6, respectively to multiply the amount of ninhydrin–N obtained, as was done by Ocio and Brookes (1990) and Muñoz et al. (2007).

Data analysis

Prior to analysis, bacteria population data were transformed us-

ing natural logarithm. A one way analysis of variance was used to estimate the relative importance of various sources of variation on bacteria population and microbial biomass (MB-C and MB-N). Means found to differ significantly were separated using the Duncan multiple range test. Pearson's correlation analysis was used to investigate the strength of relationship between the main effects and microbe population and microbial biomass.

Results

Fourteen similar bacteria species were isolated from the soils of the different plantations (Table 1a). *Staphylococcus* species (e.g. *S. aureus* and *S. epiderdimis*) were present in the two soil depths of most plantations during most of the seasons (Table 1a). The *Proteus* species (e.g. *P. mirabilis* and *P. vulgaris*) were more abundant in plantations of 13 to 21 years old. *Listeria monocytogenes* was encountered in all the plantations during all seasons, except in the 16 year-old plantation (Table 1a). *Bacillus* spp, *Nitrosococcus* spp and *Corynebacterium diptheriae* occurred mostly at the soil depths of 0–15 cm in most plantations. *Clostridium sporogenes* and *Escherichia coli* occurred only at the soil depths of 15–30 and 0–15 cm in 13 and 16 year-old plantations, respectively, during the onset of dry season (Table 1a).

Table 1a. Bacteria species isolated from the soils of *Gmelina arborea* plantations of different ages across different seasons in tropical rainforest region, Nigeria

Soil depth (cm)		Plantation age (years)					
		25	23	21	19	16	13
Onset of rainy season (April)	0–15	*Staphylococcus epiderdimis*, *Nitrosococcus* spp, *S. aureus*	*S. aureus*, *Bacillus cereus*, *Listeria monocytogenes*	*B. cereus*, *S. aureus*, *S. pyogenes*, *L. monocytogenes*	*Serretia marcescens*, *Nitrosococcus* spp, *P. mirabilis*	*Proteus mirabilis*, *S. epiderdimis*, *Nitrosococcus* spp	*P. mirabilis*, *S. aureus*, *L. monocytogenes*
	15–30	*Streptococcus pyogenes*, *L. monocytogenes*	*L. monocytogenes*, *Corynebacterium diptheriae*, *S. Pyogenes*	*S. pneumoniae*, *P. vulgaris*, *S. pyogenes*	*C. diptheriae*, *P. mirabilis*, *S. aureus*	*S. aureus*, *C. diptheriae*, *P. mirabilis*	*B. cereus*, *S. aureus*, *L. monocytogenes*
Peak of rainy season (September)	0–15	*S. pyogenes*, *S. epiderdimis*, *Nitrosococcus* spp, *S. aureus*	*S. pyogenes*, *L. monocytogenes*, *Nitrosococcus* spp	*S. pyogenes*, *B. cereus*, *S. marcescens*, *L. monocytogenes*	*S. pyogenes*, *P. mirabilis*, *Nitrosococcus* spp	*P. mirabilis*, *S. aureus*, *Nitrosococcus* spp	*P. mirabilis*, *B.* spp, *S. epiderdimis*
	15–30	*S. aureus*, *S. pyogenes*	*S. aureus*, *P. mirabilis*	*S. pneumoniae*, *P. vulgaris*, *S. aureus*	*C. diptheriae*, *S. pnuemoniae*, *S. epiderdimis*	*Nitrosococcus* spp, *S. aureus*, *C. diptheriae*	*S. pyogenes*, *P. mirabilis*, *S. marcescens*
Onset of dry season (November)	0–15	*S. aureus*, *L. monocytogenes*, *Nitrosococcus* spp	*S. aureus*, *Nitrosococcus* spp, *B. cereus*	*P. mirabilis*, *C. diptheriae*, *S. marcescens*	*S. pyogenes*, *C. diptheriae*, *L. monocytogenes*	*P. vulgaris*, *Escherichia coli*, *S. pyogenes*	*B. megaterium*, *Nitrosococcus* spp, *P. vulgaris*
	15–30	*B. cereus*, *S. pyogenes*, *L. monocytogenes*	*S. pyogenes*, *S. aureus*, *L. monocytogenes*	*S. pyogenes*, *Nitrosococcus* spp, *S. aureus*	*P. mirabilis*, *S. aureus*, *L. monocytogenes*	*S. faecalis*, *P. vulgaris*, *C. diptheriae*	*Clostridium sporogenes*, *C. diptheriae*, *L. monocytogenes*
Peak of dry season (March)	0–15	*S. pyogenes*, *Nitrosococcus* spp, *S. aureus*, *S. epiderdimis*	*S. pyogenes*, *L. monocytogenes*, *Nitrosococcus* spp, *P. mirabilis*	*S. pyogenes*, *Bacillus* spp, *L. monocytogenes*, *S. marscescens*	*S. pyogenes*, *P. mirabilis*, *S. aureus*	*P. mirabilis*, *S. aureus*, *Nitrosococcus* spp	*P. mirabilis*, *Bacillus* spp, *S. epiderdimis*, *S. aureus*
	15–30	*S. aureus*, *S. Pyogenes*	*Staphylococcus aureus*	*S. aureus*, *P. vulgaris*, *S. pneumoniae*	*S. epiderdimis*, *S. aureus*, *C. diptheriae*	*C. diptheriae*, *Nitrosococcus* spp, *S. aureus*	*S. pyogenes*, *P. mirabilis*, *S. marcescens*

Bacteria (microbe) population decreased with increasing soil depth (Table 1b). During the rainy season, the mean bacteria population for all plantations varied between 50.11 and 63.67×10^4 cfu·mL^{-1} at soil depth of 0–15 cm and between 24.94 and 31.72 $\times10^4$ cfu·mL^{-1} at soil depth of 15–30 cm (Table 1b). During the dry season, the mean population decreased from the range of 25.77 to 37.44 $\times10^4$ cfu·mL^{-1} at soil depth of 0–15 cm to 14.56 to 25.77 $\times10^4$ cfu·mL^{-1} at soil depth of 15–30 cm. The effect of plantation age on bacteria populations was not significant ($p \geq 0.05$). In all plantations and seasons, the bacteria population was significantly higher ($p < 0.05$) at soil depth of 0–15 cm than at 15–30 cm. Seasonal variation had a significant ($p <$ 0.05) effect on microbe populations, with the highest microbe abundance during the peak of the rainy season and lowest abundance during the peak of the dry season.

Six fungi species were isolated from the two soils depths of

the plantations (Table 2). The most abundant and diverse fungi species was *Aspergillus* species, which occurred in the two soil depths of most of the plantations during all seasons (Table 2). *Rhizophus stolonifer* was recorded mostly at 15–30 cm soil depth in few plantations while *Penicillum* spp were almost entirely restricted to 0–15 cm soil depths of most plantations. *Fusarium* spp was recorded almost entirely at 21 year-old plantations (Table 2).

Table 1b. Effect of plantation age, seasonal variation and soil depths on bacteria population in *Gmelina arborea* plantations (cfu·mL^{-1}×10^{-4})

Measurement period (seasons)	Soil depth (cm)	Plantation age (years) 25	23	21	19	16	13	Mean
Onset of rainy season (April)	0–15	51.00±2.0	49.67±3.18	52.67±2.85	49.33±4.63	47.67±3.84	50.33±5.70	50.11±1.39
	15–30	22.67±2.85	25.67±2.85	26.67±2.60	27.00±3.21	26.67±3.33	21.00±2.08	24.94±1.13
Peak of rainy season (Sept.)	0–15	67.00±1.53	64.00±4.00	63.67±1.86	62.67±2.19	64.33±7.17	60.33±4.37	63.67±1.46
	15–30	30.33±2.91	32.33±3.84	30.67±0.88	33.67±4.63	32.33±2.73	31.00±5.57	31.72±1.31
Onset of dry season (Nov.)	0–15	41.67±2.33	38.00±1.53	34.00±1.15	39.33±1.67	36.33±2.03	35.33±2.73	37.44±0.99
	15–30	18.67±2.03	19.00±1.53	18.33±0.89	20.00±1.15	20.33±0.67	22.33±1.45	19.78±0.57
Peak of dry season (March)	0–15	25.33±0.67	24.33±1.45	23.67±1.20	27.33±2.33	28.33±1.20	25.67±1.33	25.77±0.64
	15–30	13.33±2.03	12.67±1.45	12.33±0.33	17.33±2.91	16.00±0.33	15.33±0.33	14.56±0.71

Notes: Each value is the mean of four replicates ± standard error of the mean.

Table 2. Fungi species isolated from the soils of *Gmelina arborea* plantations of different ages across different seasons in tropical rainforest region, Nigeria

Soil depth (cm)		Plantation age (years) 25	23	21	19	16	13
Onset of rainy season (April)	0–15	*Aspergillus flavus*, *A. niger*, *Penicillum* spp	*A. niger*, *Penicillum* spp, *A. fumigatus*	*A. flavus*, *A. fumigatus*, *Penicillum* spp, *Fusarium* spp	*A. niger*, *A. flavus*, *A. fumigatus*	*A. niger*, *A. fumigatus*, *Penicillum* spp	*A. niger*, *A. fumigatus*, *Fusarium* spp
	15–30	*Rhizophus stolonifer*, *A. niger*	*R. stolonifer*, *A. fumigatus*	*A. niger*, *A. flavus*, *A. fumigatus*	*A. niger*, *A. fumigatus*, *A. flavus*	*A. niger*, *A. fumigatus*, *A. flavus*	*A. niger*, *A. fumigatus*
Peak of rainy season (September)	0–15	*Penicillium* spp, *A. niger*, *A. fumigates*	*A. flavus*, *Penicillum* spp, *A. niger*	*A. niger*, *Fusarium* spp	*A. flavus*, *A. niger*, *A. fumigatus*	*A. niger*, *A. fumigatus*	*A. fumigatus*, *Penicillum* spp, *A. niger*
	15–30	*A. niger*	*A. fumigatus*, *A. flavus*	*A. niger*, *Fusarium* spp, *R. stolonifer*	*A. flavus*, *A. niger*, *A. fumigatus*	*A. niger*	*A. niger*, *A. fumigatus*, *R. stolonifer*
Onset of dry season (November)	0–15	*Penicillum* spp, *A. niger*, *A. fumigates*	*A. flavus*, *A. fumigatus*, *A. niger*, *Penicillum* spp	*A. flavus*, *A. niger*, *A. fumigatus*, *Fusarium* spp	*A. niger*, *A. flavus*, *Penicillum* spp, *A. fumigatus*	*A. niger*, *A. fumigatus*, *Penicillum* spp	*A. niger*, *A. fumigatus*, *R. stolonifer*
	15–30	*A. niger*, *A. fumigates*	*A. flavus*, *A. fumigatus*, *R. stolonifer*	*A. niger*, *Fusarium* spp, *R. stolonifer*	*A. niger*, *A. fumigatus*, *A. flavus*	*A. niger*, *A. fumigatus*, *Penicillum* spp	*A. niger*, *A. fumigatus*, *R. stolonifer*
Peak of dry season (March)	0–15	*Penicillum* spp, *A. niger*, *A. fumigates*	*Penicillum* spp, *A. niger*, *A. flavus*	*Penicillum* spp, *A. niger*, *A. fumigatus*	*A. flavus*, *A. niger*, *A. fumigatus*	*R. stolonifer*, *A. niger*	*A. niger*, *A. fumigatus*, *R. stolonifer*
	15–30	*A. niger*, *A. fumigates*	*A. flavus*, *A. niger*, *A. fumigatus*	*A. niger*, *R. stolonifer*	*A. flavus*, *A. niger*, *A. fumigatus*	*A. flavus*, *A. niger*, *A. fumigatus*	*A. niger*, *A. fumigatus*, *R. stolonifer*

The trend of MB-C and MB-N values of the sampled plantations is presented in Figs. 1*a* & *b*. Microbial biomass was higher during the rainy season than the dry season and at 0–15 cm soil depths than at 15–30 cm. In all plantations, there was a drastic increase in MB-C and MB-N at both soil depths from dry season to rainy season. At 0–15 cm soil depths, mean MB-C increased from 50.74 μg·g^{-1} at the peak of the dry season to 99.58 μg·g^{-1} at the peak of the rainy season, while it increased from 36.22 to 75.31μg·g^{-1} at the 15–30 cm soil depths between the same seasonal periods (Table 3a). Also, MB-N at 0–15 cm soil depths increased from 7.5 μg·g^{-1} during the peak of dry season to 14.8 μg·g^{-1} during the peak of rainy season, while at 15–30 cm soil depth, it increased from 5.4 to 11.2 μg·g^{-1} at the peak of the dry season and the peak of the rainy season, respectively (Table 3b). While the effect of season and soil depth significantly affected MB-C and MB-N values ($p < 0.05$), the effect of plantation age on MB-C and MB-N was not significant ($p \geq 0.05$) (Table 4). MB-C and MB-N values at the two soil depths during the rainy season were significantly higher ($p < 0.05$) than during the dry season. The MB-C and MB-N values at the peak of the rainy season were significantly higher than those of other seasons (Table 4). The increase in MB-C and MB-N from the peak of the dry season to the onset of the rainy season (i.e. transition from dry to rainy season) was more pronounced than between any other pair

of seasons (Figs. 1a & b). Irrespective of the season of the year and the age of the plantation, MB-C and MB-N values at 0–15 cm soil depth were significantly higher than those at 15–30 cm. Positive and significant correlations were found between season and microbial indices (i.e. MB-C, MB-N and microbe population) in all plantations, with correlation coefficients ranging from 0.702 to 0.786. Correlations between microbe populations and microbial biomass in all plantations were also positive and significant (range: 0.841 to 0.905). However, the coefficient was higher (range: 0.828 to 0.945) at 0–15 cm soil depths than at 15–30 cm (range: 0.706 to 0.886).

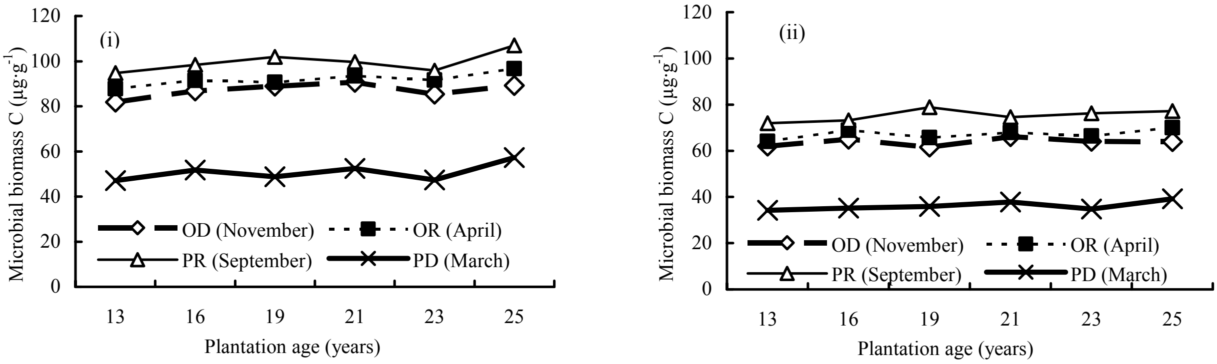

Fig. 1a: Microbial Biomass Carbon in soils of age series *Gmelina arborea* plantations at (i) 0–15cm and (ii) 15–30 cm during peak dry season (PD), onset of rainy season (OR), peak rainy season (PR) and onset of dry season (OD)

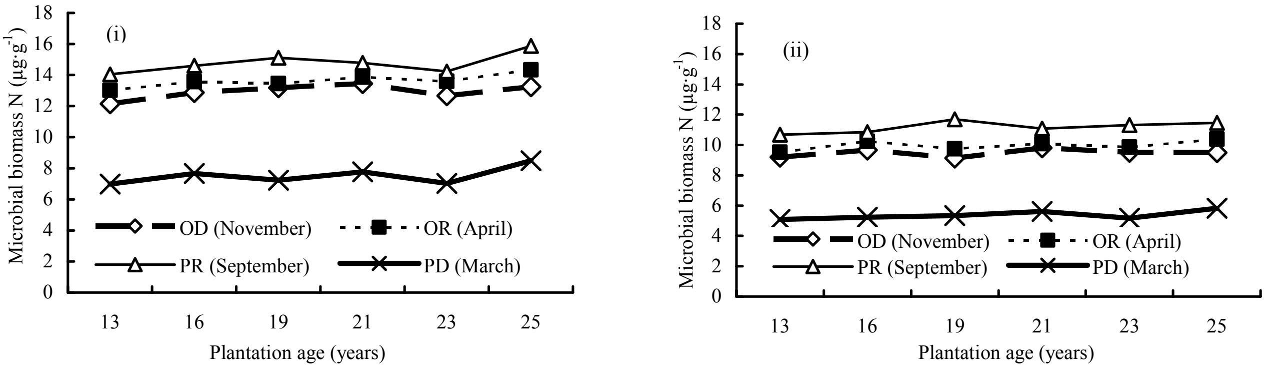

Fig. 1b: Microbial Biomass Nitrogen in soils of age series *Gmelina arborea* plantations at (i) 0–15cm and (ii) 15–30 cm during peak dry season (PD), onset of rainy season (OR), peak rainy season (PR) and onset of dry season (OD)

Table 3a. Effect of plantation age, seasonal variation and soil depths on MB-C values in *Gmelina arborea* plantations of different ages in tropical rainforest region, Nigeria ($\mu g \cdot g^{-1}$ soil)

Soil depth (cm)		Plantation age (years)						
		25	23	21	19	16	13	Mean
Onset of rainy season (April)	0–15	96.62±2.44	91.66±1.60	93.41±1.09	90.62±4.80	91.45±3.01	87.73±2.67	91.92±1.18
	15–30	69.96±3.41	66.44±2.33	67.99±2.33	65.72±1.94	68.92±2.61	64.07±2.47	67.18±1.01
Peak of rainy season (September)	0–15	106.95±4.94	95.89±2.51	99.72±2.77	101.89±2.85	98.37±2.44	94.65±1.66	99.58±1.43
	15–30	77.19±2.52	76.16±2.28	74.61±1.08	78.84±3.52	73.16±2.81	71.92±1.89	75.31±1.03
Onset of dry season (November)	0–15	89.18±3.67	85.35±1.77	90.62±2.44	88.87±2.38	86.80±1.09	82.54±2.35	87.11±1.09
	15–30	63.96±0.73	64.07±2.14	66.13±2.56	61.59±2.07	65.10±2.95	62.00±2.11	63.81±0.89
Peak of dry season (March)	0–15	57.25±1.81	47.33±1.81	52.39±3.63	48.77±2.78	51.67±0.72	47.02±0.81	50.74±1.14
	15–30	39.27±1.91	34.82±0.72	37.82±0.36	35.96±2.52	35.24±0.99	34.20±1.52	36.22±0.68

Note: Each value is the mean of four replicates ± standard error of the mean.

Table 3b. Effect of plantation age, seasonal variation and soil depths on MB-N values in *Gmelina arborea* plantations of different ages in tropical

rainforest region, Nigeria (μg·g^{-1} soil)

Soil depth (cm)		Plantation age (years)						
		25	23	21	19	16	13	Mean
Onset of rainy season (April)	0–15	14.34±0.36	13.60±0.24	13.86±0.16	13.45±0.71	13.57±0.45	13.02±0.40	13.64±0.17
	15–30	10.38±0.51	9.86±0.35	10.09±0.35	9.75±0.29	10.23±0.39	9.51±0.37	9.97±0.15
Peak of rainy season (September)	0–15	15.87±0.73	14.23±0.37	14.80±0.41	15.12±0.42	14.60±0.36	14.05±0.25	14.78±0.21
	15–30	11.45±0.37	11.30±0.34	11.07±0.16	11.70±0.52	10.86±0.42	10.67±0.28	11.18±0.15
Onset of dry season (November)	0–15	13.23±0.54	12.67±0.26	13.45±0.36	13.19±0.35	12.88±0.16	12.24±0.35	12.93±0.16
	15–30	9.49±0.11	9.51±0.32	9.81±0.38	9.14±0.31	9.66±0.44	9.20±0.31	9.47±0.13
Peak of dry season (March)	0–15	8.49±0.27	7.02±0.27	7.77±0.54	7.24±0.41	7.67±0.11	6.98±0.12	7.53±0.17
	15–30	5.83±0.28	5.17±0.11	5.61±0.05	5.34±0.37	5.23±0.15	5.08±0.23	5.37±0.10

Notes: Each value is the mean of four replicates ± standard error of the mean.

Table 4. The results of analysis of variance for the effect of land-use systems and seasonal variations on microbe population, MB-C and MB-N values of the oils of the study ecosystems

Plantation age (years)	Microbe population (cfu·mL^{-1})×10^4	Microbial Biomass –N (μg·g^{-1} soil)	Microbial Biomass – C (μg·g^{-1} soil)	Different rainy season	Microbe population (cfu·mL^{-1})×10^4	Microbial Biomass - N –N (μg·g^{-1} soil)	Microbial Biomass–C (μg·g^{-1} soil)
25	33.75a	11.14a	75.05a	Apr.	37.53b	11.80b	79.55b
23	33.21a	10.42a	70.22a	Sept.	47.69a	12.98a	87.45a
21	32.75a	10.81a	72.84a	Nov.	28.61c	11.20b	75.46b
19	34.58a	10.61a	71.53a	Mar.	20.17d	6.45c	43.48c
16	34.04a	10.59a	71.34a	-	-	-	-
13	32.67a	10.08a	67.93a	-	-	-	-

Notes: Values followed by similar letters are not significantly different ($p < 0.05$).

Table 5. Comparison of biological and chemical properties of the soils of *Gmelina arborea* plantation and adjacent degraded natural forest in Oluwa forest reserve, Nigeria

Soil microbial and chemical properties	*Gmelina* plantation (25 years)		Degraded forest	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Microbe population (cfu·mL^{-1})×10^4	43.51	20.0	37.42	14.47
Microbial biomass C (μg·g^{-1} soil)	87.50	62.59	84.11	11.88
Microbial biomass N (μg·g^{-1} soil)	12.98	9.29	12.42	9.35
Bulk density (Mg· m^{-3})	1.42	–	1.36	–
pH	7.1	6.8	6.7	6.5
Organic matter (%)	3.38	2.93	3.42	2.80
Total N (%)	0.41	0.33	0.36	0.32
Available P (mg·kg^{-1})	9.57	8.61	10.77	10.23
CEC (cmol·kg^{-1})	10.25	10.29	11.99	5.34
Exchangeable K (cmol·kg^{-1})	0.28	0.27	0.35	0.30
Exchangeable Mg (cmol·kg^{-1})	1.77	1.68	1.91	1.66
Exchangeable Ca (cmol·kg^{-1})	1.03	0.97	1.05	0.94
Exchangeable Na (cmol·kg^{-1})	0.21	0.25	0.25	0.27

Discussion

Most of the fungi species isolated from the plantation soils are saprophytes, producing enzymes that break down organic matter into absorbable nutrients. Together with bacteria, these fungi are to a large extent, responsible for decomposition of plant and animal residue in forest ecosystems. Bacteria populations in this study are slightly higher than the values reported for some *Gmelina* plantations (Oseni et al. 2007; Arunachalam and Arunachalam 2000). Bacteria population reported here was affected by seasons and soil depth, which agrees with the reports of Arunachalam and Arunachalam (2000) and Oseni et al. (2007). A high bacteria population during the rainy season could be attributed to favourable moisture and temperature conditions, which are ideal for litter decomposition. On the other hand, the low bacteria population during the dry season reported in this study

could be attributed to the combined effects of low soil moisture occasioned by low/absence of rainfall and high temperature, which adversely affect microbial growth and activity, and makes soil litter difficult to decompose.

Available reports indicate a wide variation in MB-C (7.6–333 $\mu g \cdot g^{-1}$) and MB-N (1.1–65 $\mu g \cdot g^{-1}$) in forest plantation soils. For example, Behera and Sahani (2003) reported a range of 166–333 $\mu g \cdot g^{-1}$ and 37–65 $\mu g \cdot g^{-1}$ for MB-C and MB-N, respectively in a 30-year-old *Eucalyptus* species plantation in India while Dutta and Agrawal (2002) reported a range of 125.0–141.6 $\mu g \cdot g^{-1}$ (MB-C) and 10.3–19.4 $\mu g \cdot g^{-1}$ (MB-N) in five 12-year-old plantations. The variation in microbial biomass could be due to differences in tree species, plantation management history, climatic conditions, soil types, soil properties, or seasonal variation (Ross et al. 1995; Singh et al. 2004; Kara et al. 2008; Skovsgaard et al. 2008). The microbial biomass values reported in this study are lower than those reported by most of the authors cited above. However, the microbial biomass values of this study are comparable to those reported by Khan and Joergensen (2007) and higher than those reported by Oseni et al. (2007). For example, Oseni et al. (2007) reported MC-B and MC-N of 7.6–68.4 $\mu g \cdot g^{-1}$ and 1.1–10.2 $\mu g \cdot g^{-1}$, respectively for *Gmelina* plantations in Ondo State, Nigeria.

Research by others suggests that where plantation age significantly affects soil microbial activity, it is usually during the early stages of plantation development. Singh et al. (2004) reported a significant increase in MB-C and MB-N from 129.3 to 363.2 $\mu g \cdot g^{-1}$ and from 20.0 to 43.1 $\mu g \cdot g^{-1}$, respectively in 4 and 6 years-old plantations, respectively. Hart et al. (1989) and Ross et al. (1995) showed that soil microbe populations and microbial biomass showed little changes in 10–25 years-old and 33 year-old plantations respectively, thus implying little further influence of age. Consequently, the non-significant effect of plantation age on microbial biomass in this study could be an indication of soil restoration in the investigated plantations. Onyekwelu et al. (2006) and Onyekwelu (2011) reported an indication of restoration and stability of soil nutrients in old growth *Gmelina* plantations in Nigeria. Another indication of soil restoration in *Gmelina* plantations is the non-significant and comparable properties of their soils with those of adjacent degraded natural forests in the study area (Table 5). Since the remaining degraded forests in Oluwa forest reserve have remained almost undisturbed since the establishment of *Gmelina* plantations (Onyekwelu et al. 2006), it can be taken that the comparable results of the two ecosystems (i.e. *Gmelina* plantations and adjacent degraded natural forest) is an indication of soil restoration in the plantation sites to pre-planting levels. This is based on the assumption that if *Gmelina* plantations had not been established, the conditions on these sites would probably be the same as those in the adjacent degraded natural forests.

This study showed that microbe population and microbial biomass (MB-C and MB-N) values were significantly affected by seasons, with higher values during the rainy season. Also, the correlation between rainfall and microbe population and microbial biomass (MB-C and MB-N) was positive, significant, and linear. Seasonal variation contributed significantly to the increasing trend of microbial indices as seasons changed from dry to wet. The high difference in rainfall between the rainy and dry seasons is one of the factors responsible for variation in soil microbe population and biomass. The moist conditions during the rainy season, coupled with high temperatures are ideal for breakdown of organic matter. Soil microbes are usually more active during warm and moist periods when decomposable organic matter is available, which explains the higher microbe populations during rainy months than during dry ones. Seasonality plays an important role in MB-C and MB-N turnover. Higher microbial biomass during the rainy season than dry season has been reported by others (Behera et al. 1991; Yang and Isham 1991) and is confirmed by the results of this study. In contrast, Sharma et al. (2004) reported that MB-C and MB-N values were higher during the dry season than rainy season. The differences in microbe population and microbial biomass of the two transitional periods were not statistically different, probably due to the similarity of rainfall and temperature conditions during these periods.

The significantly decreasing trend of microbe population and microbial biomass (i.e. MB-C and MB-N) values with increasing soil depth is an indication of higher microbial activity at the upper soil horizon (0–15 cm) than at lower one (15–30 cm). This can be attributed to the higher concentration of organic matter at the soil surface. This is to be expected since the upper soil horizon is the place of accumulation and decomposition of mineral and organic matter as well as incorporation of decomposed organic and mineral matter into the soil (FAO 1998). The rapid decomposition and concentration of organic and mineral matter at or near the upper soil horizon could be explained by the activities of soil microbes and soil macro-organisms (e.g. earthworms) in this zone and the warm and moist conditions on the forest floor (Onyekwelu et al. 2006).

Conclusions

The development (age) of *G. arborea* plantations in Oluwa forest reserve had no adverse effect on soil microbial activities. Microbial indices of the investigated *Gmelina* plantation soils were similar to those of the soils of adjacent degraded natural forest, which could imply that the microbial indices of the plantation soils have been restored to pre-planting levels. This similarity, coupled with the non-significant effect of plantation age on microbe population and microbial biomass suggests that there are no significant or noticeable negative changes in soil biological conditions in the *Gmelina* plantations. Consequently, it is concluded that the *Gmelina* plantations in the study area are sustainable. Most of the microbial activities in *Gmelina* plantations took place during the peak of the rainy season as well as the seasonal transition periods. Irrespective of the season of the year and the age of the plantation, microbe population and biomass (MB-C and MB-N) values were significantly higher at 0–15 cm soil depth than at 15–30 cm. Thus, the upper soil horizon (0-15 cm) is the region of most microbial activities in the soil under *Gmelina* plantations.

Acknowledgement
I am grateful to Alexander von Humboldt Foundation (AvH), Germany for Fellowship award under the framework of AvH research fellowship. Mr. F. A. Faruwa and J. A. Muraina are appreciated for their assistance in field data collection. Dr. O. A. Oseni assisted with laboratory analyses. Thanks to the management of Ondo State Afforestation Project for permission to conduct the research within their forest reserve.

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